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Elemental composition of soils and tissues of natural jojoba populations of Baja California, Mexico

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Soil–plant relationships of natural jojoba (*Simmondsia chinensis* (Link) Schneider) populations were investigated by analyzing soils and young tissues of three jojoba ecotypes at five sites in Baja California, Mexico. Jojoba occurred in non-saline to slightly saline and near-neutral to alkaline soils. Concentrations of K, Na and B in soil saturation extracts were normal for arid-zone soils, while Ca and Mg were low. Elemental concentrations in young jojoba tissues were generally within the sufficiency ranges proposed for commercial plantations. Results suggest that jojoba excludes Na^+ from tissues even when rooting medium salinity is low.

Introduction

Jojoba (*Simmondsia chinensis* (Link) Schneider) is a drought-tolerant shrub native to the dry regions of the west coast of North America. Jojoba seeds contain 40–60% high-quality liquid wax that resists extreme heat and pressure (Miwa, 1971; Yermanos, 1975). The industrial importance of the wax gives the species a high economic potential (Naqvi, Goldstein *et al.*, 1988). There is increasing interest in its intensive cultivation in the dry regions of the world. Jojoba has not been domesticated completely and basic knowledge of its soil–plant relations is required for the development of appropriate agrotechniques.

It has been suggested that the extreme drought tolerance of jojoba is related to its resistance to salinity in the rooting medium (Tal, Rosental *et al.*, 1979). However, no information has been available on soil salinity or mineral nutrition of native jojoba in natural ecosystems (Tal, Rosental *et al.*, 1979). The objectives of the present work were to assess soil salinity, and to evaluate and correlate the concentrations of some nutrient elements in soils and tissues of different jojoba ecotypes.

Materials and methods

Four sites along a transect crossing the Baja California peninsula (La Misión, Guadalupe, Ojos Negros and San Felipe), and a fifth site (Cataviña) in the Central Desert region were chosen for sampling the soils and tissues of native jojoba (Fig. 1; Table 1). The sites lie

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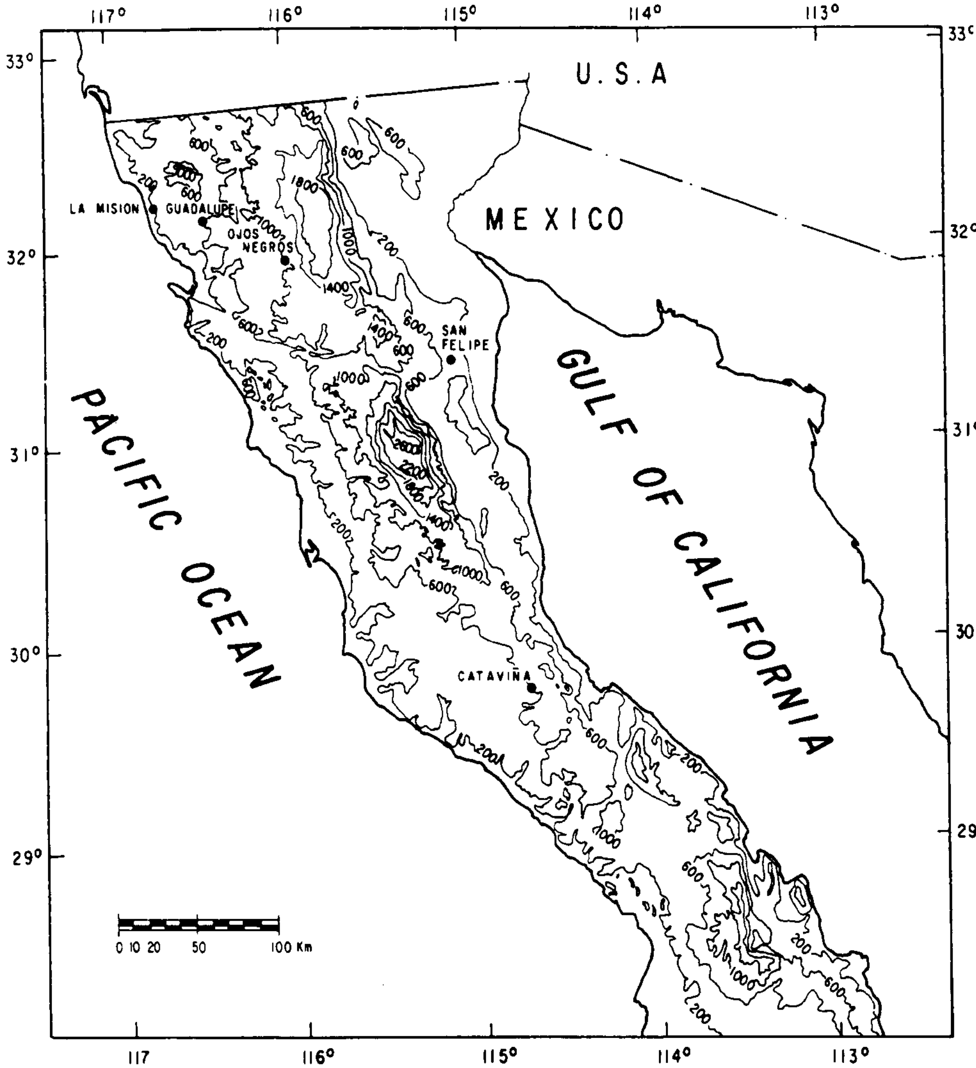

Figure 1. Topographic map of the State of Baja California, Mexico, showing the location of jojoba soil and tissue sampling sites. Altitudes are in meters above sea level.

within a region of great phenotypic diversity of jojoba and range from temperate coastal to severe desert climatic conditions. These natural jojoba populations represent the three ecotypes found in the State of Baja California, Mexico, as defined by Castellón, Delgadillo *et al.* (1990). The populations at La Misión and Ojos Negros are extensive and dense and are harvested profitably by hand.

The area sampled at each site varied according to the population density of jojoba. Desert (San Felipe and Cataviña) populations required a sampling area of several ha, while <1 ha sufficed for the populations from more mesic locations (La Misión, Guadalupe, and Ojos Negros). Tissue samples, taken from six adult male and female plants during late January and early February 1988, consisted of 2–3 young shoots (suckers 10–20 cm long arising from the crown of the plant) produced during the winter growth period. The plant samples collected in the field were brought to the laboratory in paper bags, washed in 0·1%

Table 1. *Jojoba tissue and soil sampling sites, Baja California, Mexico*

Site (description)	Ecotype*	Physiographic position	Parent material†	Mean annual precipitation‡ (mm)	Mean annual temperature‡ (°C)
La Misión (coastal canyon)	Coastal	Steep canyon wall	Basalt	205	18·0
Guadalupe (inland valley)	Mediterranean	Hillside	Granodiorite	304	17·0
Ojos Negros (high valley)	Mediterranean	Medium backslope	Granite	245	16·1
San Felipe (low desert)	Desert	In wash	Alluvium (sand)	65	22·5
Cataviña (high desert)	Desert	Medium backslope	Granite	110	19·0

* As defined by Castellón, Delgadillo *et al.* (1990).
† From Gastil, Phillips *et al.* (1975).
‡ Nearest weather station. Source: Secretaría de Agricultura y Recursos Hidraulicos.

Liqui-Nox detergent solution, rinsed thoroughly with distilled water and dried in a forced-draft oven at 60°C. Tissues were ground to pass a #100 mesh, and 250-mg subsamples were digested in concentrated HNO_3 and HNO_3:$HClO_4$ (2:1) as described by Ganje & Page (1974).

Soils were sampled in spaces between shrubs within the area where plant tissues were sampled, but no attempt was made to associate particular soil and plant samples. Using an 8-cm diameter auger, four subsites (within a single uniform soil unit) were sampled by obtaining 500 g soil from 0–10, 10–30, 30–50 and 50–100 cm depths (except at San Felipe, where the very dry sandy soil from the 50–100 cm depth sliped out of the auger before reaching the surface). Soil samples were air-dried and passed through a 2-mm sieve. Saturated pastes were prepared with deionized water and soil solution was extracted as described by Rhoades (1982). The pH of the saturated pastes and the electrical conductivity of the saturation extracts (EC_e) were measured using a Selectro-Mark Analyzer model 4503 (Markson Science, Phoenix, AZ). Soil saturation extracts and plant tissue digests were analyzed for Ca, Mg, Na, K, P, B, Mn, Fe, Zn, Cu and Al by using an inductively coupled argon plasma spectrometer (Jarrell-Ash AtomComp Series 8000 ICAP).

Results

The chemical properties of soils supporting significant natural populations of jojoba in Baja California are given in Table 2. The results demonstrate that native jojoba generally grows in non-saline soils having moderately acid to slightly alkaline reaction (U.S. Salinity Laboratory Staff, 1954; Committee on Terminology, 1984). The most extreme site, San Felipe, had strongly alkaline soils. Both pH and EC_e tended to increase with depth consistently with increasing concentrations of Na^+ and Ca^{2+}.

Concentrations of K, Na and B in saturation extracts reported in Table 2 were within normal ranges, while those of Ca and Mg were usually low for arid and semi-arid environments (U.S. Salinity Laboratory Staff, 1954; Reisenauer, 1964; Barber, 1984; Bingham, Arkley *et al.*, 1970). Saturation extract P concentrations at La Misión, Guadalupe, Cataviña and San Felipe were low, but that at Ojos Negros was adequate for plant growth (Mengel & Kirkby, 1982; Barber, 1984).

Saturation extract Fe and Mn concentrations generally ranged between 0·01 and 0·10 mg l^{-1}, Cu and Zn were less than 0·05 mg l^{-1}, and Al was less than 0·10 mg l^{-1}. These low concentrations are probably explained by the neutral or alkaline pH values of these soils (Table 2). At La Misión where pH was relatively low, concentrations as high as 4·4, 0·22, 0·04, 0·20, and 4·75 mg l^{-1} were observed for Fe, Mn, Cu, Zn and Al, respectively.

Analysis of variance showed that the concentrations of nutrient elements differed significantly ($p \leq 0{\cdot}05$) in tissue from different sites (Table 3). Although male jojoba plants showed consistently higher concentrations of Ca, Mg, K, B, Fe, Mn and Zn, differences between male and female plants within a site were not significantly different. However, female plants tended to accumulate higher Na^+ concentrations than male plants (data not shown). The K/Ca concentration ratio decreased from 5·1 to 1·3 in the transect across the northern part of the peninsula (La Misión to San Felipe) while K/Mg (~2·4) and K/P (~11) were more nearly constant. Tissue B concentrations were significantly higher at San Felipe than those observed at other sites (Table 3). The higher pH values at that site (Table 2) should result in reduced availability of soluble B species (Bingham, Arkley *et al.*, 1970). Available data are insufficient to explain the higher B concentrations observed in young tissues at this site.

The concentrations of K, Na, P, B, Fe and Zn in young jojoba tissue reported in Table 3 were within the nutrient sufficiency ranges proposed for commercial jojoba plantings based on fully expanded leaf tissue samples collected in summer (Eberhardt, 1989). The concentrations of Ca and Mg in tissues at all sites were lower than the proposed lower

Table 2. *Chemical properties of soils supporting natural populations of jojoba in Baja California, Mexico. Each value represents the range (pH) or mean ± standard error of the mean of four soil samples. Elemental concentrations were measured by inductively coupled argon plasma spectrometry*

Sample depth (cm)	pH (saturated paste)	EC_e dSm^{-1}	$mg\,l^{-1}$ saturation extract Ca	Mg	Na	K	P	B
			La Misión					
0– 10	6·0–6·8	0·33 ± 0·03	23·3 ± 5·32	8·50 ± 1·57	37·0 ± 8·79	5·04 ± 1·52	0·22 ± 0·11	0·52 ± 0·14
10– 30	6·1–7·0	0·41 ± 0·24	29·8 ± 4·72	31·0 ± 18·9	37·4 ± 16·7	6·00 ± 1·51	0·38 ± 0·26	0·48 ± 0·35
30– 50	6·7–7·6	0·73 ± 0·17	29·0 ± 9·17	17·1 ± 6·40	81·6 ± 26·0	5·19 ± 1·64	0·65 ± 0·16	0·51
50–100	6·4–7·5	0·74 ± 0·22	26·2 ± 7·66	17·0 ± 5·37	103 ± 30·0	5·48 ± 2·58	0·25 ± 0·09	1·67 ± 1·23
			Guadalupe					
0– 10	6·4–6·8	0·44 ± 0·04	19·7 ± 1·87	8·18 ± 1·48	61·5 ± 9·47	6·04 ± 0·44	0·18 ± 0·00	1·70 ± 0·46
10– 30	6·5–6·9	0·60 ± 0·10	32·9 ± 11.0	15·0 ± 7·28	87·7 ± 10·1	3·19 ± 0·80	0·14 ± 0·04	1·51 ± 0·31
30– 50	6·7–7·3	1·83 ± 0·52	69·7 ± 29·2	27·5 ± 11·4	208 ± 78·6	1·34 ± 0·33	0·06 ± 0·01	0·92 ± 0·01
50–100	7·2–7·7	7·20 ± 1·64	411 ± 131	104 ± 21·6	690 ± 102	3·65 ± 0·13	0·03 ± 0·01	0·94 ± 0·18
			Ojos Negros					
0– 10	6·8–7·4	0·28 ± 0·04	24·5 ± 6·42	9·49 ± 2·12	18·4 ± 1·40	7·81 ± 1·88	1·36 ± 0·39	0·46 ± 0·10
10– 30	6·9–7·8	0·36 ± 0·13	20·8 ± 5·02	19·8 ± 11·7	24·7 ± 4·32	6·32 ± 2·47	1·55 ± 0·41	0·80 ± 0·32
30– 50	7·2–7·8	0·42 ± 0·13	34·4 ± 10·9	16·8 ± 6·33	33·1 ± 9·61	9·79 ± 6·48	1·84 ± 0·84	0·71 ± 0·38
50–100	7·7–8·1	0·68 ± 0·05	51·1 ± 6·92	24·7 ± 4·92	66·4 ± 11·3	4·84 ± 2·23	1·13 ± 0·24	1·72 ± 0·66
			San Felipe					
0– 10	8·2–8·5	0·66 ± 0·31	86·8 ± 43·6	12·0 ± 8·04	26·3 ± 8·39	17·5 ± 2·6	0·25 ± 0·08	0·80 ± 0·20
10– 30	8·0–8·6	0·81 ± 0·50	108 ± 70·6	14·1 ± 9·85	26·0 ± 11·4	16·8 ± 12·2	0·12 ± 0·05	0·81 ± 0·32
30– 50	8·1–8·5	0·66 ± 0·18	90·4 ± 35·7	12·3 ± 5·21	24·2 ± 4·18	14·8 ± 6·03	0·12 ± 0·03	0·72 ± 0·25
			Cataviña					
0– 10	6·1–7·8	0·41 ± 0·10	35·1 ± 15·7	7·14 ± 3·25	43·4 ± 8·26	4·38 ± 0·59	0·23 ± 0·14	1·04 ± 0·34
10– 30	6·1–7·8	0·43 ± 0·09	37·4 ± 19·1	5·66 ± 3·37	54·2 ± 12·4	3·96 ± 1·13	0·31 ± 0·12	1·46 ± 0·19
30– 50	5·6–8·0	0·56 ± 0·16	27·4 ± 11·2	5·57 ± 1·14	83·1 ± 35·6	4·61 ± 1·27	0·19 ± 0·07	1·63 ± 0·23
50–100	6·6–7·8	0·70 ± 0·21	39·3 ± 3·23	9·36 ± 2·98	84·3 ± 53·4	5·74 ± 2·42	0·17 ± 0·06	1·08 ± 0·31

Table 3. *Concentration of nutrient elements in young shoot tissue from adult jojoba plants of natural populations growing in Baja California, Mexico. Elemental concentration was measured in tissue digests by inductively coupled argon plasma spectrometry. Each value is the mean of twelve plant samples (six male and six female); the standard error of the mean is shown beneath each value. Values followed by an asterisk (*) are significantly different from the lowest value in that column* ($p < 0{\cdot}05$)

	mg kg^{-1} plant tissue									
Site	Ca	Mg	Na	K	P	B	Fe	Mn	Cu	Zn
La Misión	3289	6110	386	16750*	1434*	57·4	37·2	51·0	4·7*	17·6
	467	352	61·8	939	112	5·31	2·51	5·71	0·48	1·89
Guadalupe	4840	5109	410	13919	1275*	52·1	40·9	58·1	4·89*	17·1
	603	442	134	976	107	4·82	5·15	9·24	0·40	1·60
Ojos Negros	5334	5039	133	10595	1018	47·3	46·0	63·1	2·95	13·8
	440	295	45·4	806	101	4·06	6·05	8·24	0·22	3·51
San Felipe	8480*	5590	1737*	11283	844	132*	35·0	109*	2·44	10·8
	1518	670	454	1519	54·0	16·5	1·82	16·9	0·29	1·17
Cataviña	7760*	5036	473	10937	1427*	76·3	32·3	71·5	3·74	15·0
	684	516	153	921	120	7·56	2·35	8·72	0·25	0·80

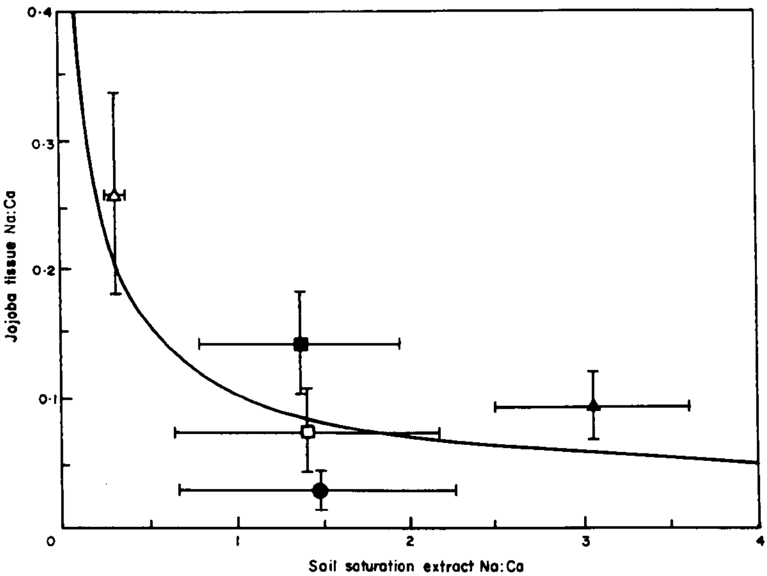

Figure 2. Relationship between average soil saturation extract Na:Ca concentration for the 10–30 cm depth increment (n = 4) and average jojoba tissue Na:Ca concentration (n = 12) at the five sampling sites ■, La Misión; ▲, Guadalupe; ●, Ojos Negros; △, San Felipe; □, Cataviña). Error bars are ±1 standard error of the mean. The equation of the line is $Y = 0{\cdot}10713X^{-0{\cdot}5564}$ ($R^2 = 0{\cdot}358$, $p < 0{\cdot}2$).

sufficiency limits (9000 and 8000 mg kg^{-1} respectively), but tissue Ca concentrations from the two desert sites were not significantly lower. The concentration of Mg in all soils and tissues was low (Tables 2, 3), suggesting a possible deficiency in this nutrient. Manganese and copper in young jojoba tissues were only slightly below the sufficiency ranges, and it is probable that deficiencies of Ca and Mn are avoided in mature tissues because these elements accumulate as tissues age.

The correlation between soil saturation extract Na:Ca and plant tissue Na:Ca concentrations showed a negative relationship ($R^2 = 0{\cdot}358$, $p < 0{\cdot}2$) for the 10- to 30-cm depth increment (Fig. 2). Although there is considerable variability in the data, the observed negative relationship suggests that jojoba excludes Na^+ and preferentially absorbs Ca^{2+} even when salinity in the rooting medium is low. Previous research in the Central Desert of Baja California has demonstrated that the highest jojoba root densities occur at 10–30 cm, and that jojoba leaf water tension is best correlated with soil water contents at that depth (unpublished data). Such results suggest that nutrient uptake is most active at the 10- to 30-cm depth during the humid winter season.

Discussion

Jojoba has attracted interest as a crop for dry regions because of its adaptation to drought, salinity, alkalinity and high temperatures (Gentry, 1958; Yermanos, Francois *et al.*, 1967; Benzioni & Dunstone, 1986). However, our results showed that across a wide region of the Baja California peninsula, natural populations of jojoba grow in non-saline, near-neutral to strongly alkaline soils.

Mature jojoba is resistant to salinity and seedlings can establish in saline rooting media. Seedlings showed 50% mortality when 10 dS m^{-1} NaCl–$CaCl_2$ solution was applied as irrigation water (Kayani, Naqvi *et al.*, 1990). However, it is unlikely that jojoba can resist

the combined effects of salinity and prolonged drought. In desert environments jojoba is found mostly in places with favorable water relations such as water courses or depressions underlain by impermeable parent material where water tends to collect. It is conspicuously absent in the harshest environments. Thus, it is unlikely that native jojoba can be found growing on salt-affected soils.

Previous studies (Yermanos, Francois *et al.*, 1967; Adams, Bingham *et al.*, 1978; Adams, Johnson *et al.*, 1977; Tal, Rosental *et al.*, 1979) have indicated that jojoba tolerates salinity by avoiding excess ion accumulation both by controlling uptake and transport to the shoot and by increasing leaf volume (succulence) (Greenway & Munns, 1980). Tal, Rosental *et al.* (1979) demonstrated that jojoba plant growth is not affected by salinity as high as 600 mmol l^{-1}, although the plants accumulated large concentrations of Na^+ and Cl^-. They also showed that those ion concentrations decreased rapidly once the plants were removed to a non-saline rooting medium. Our results suggest that Na^+ is excluded from young jojoba shoots even when soil salinity is low. However, because native jojoba occurs in very dry but not saline environments, it is possible that its salinity tolerance is a result of its drought adaptation and not vice versa.

Gentry (1958) indicated that jojoba soils have an abundance of phosphorus. Phosphorus concentrations in soil saturation extracts reported here were below sufficiency ranges at all but one site, and tissue P concentrations were near the lower limit of sufficiency. Thus, P supply to jojoba appeared to be adequate but not abundant. Magnesium was the only nutrient reported in the present study that may have been limiting jojoba growth and production. Further research may help to understand better the ecology and mineral nutrition of native jojoba in Baja California.

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